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AUTOMATED AERIAL REFUELING RESEARCH SUMMARY PRESENTATION

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OCTOBER 2003

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14. ABSTRACT

Briefing reports on multi-vehicle wind tunnel tests conducted by Bihrle to obtain interaction data between a KC-135 tanker and a UAV receiver. The data will be used to develop a refueling simulation to evaluate controllability and preliminary automated designs for UAV refueling. The briefing discusses use of this data with a combination of automatic refueling and collision avoidance. This is very preliminary data on interactions. It has military application for advanced UAV refueling.

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Automated Aerial Refueling
Oct 2003

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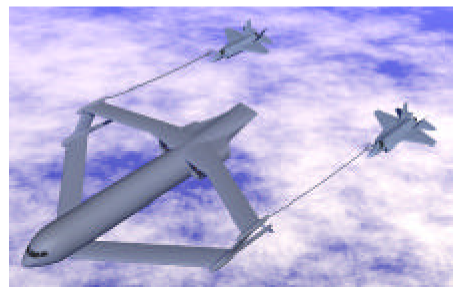
This presentation provides an overview of automated aerial refueling research being conducted by the Air Force Research Laboratory.

Automated Aerial Refueling

Objectives

- **Develop and Flight Validate Automated Aerial Refueling Capability for UAVs**
- **Identify and Validate Appropriate Mix of Automatic and Manual Control for Adverse Weather Refueling for Manned Aircraft**



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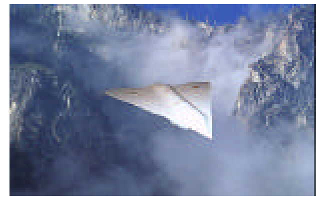
Objectives of the research are 1) to develop and flight validate automated aerial refueling capabilities for UAVs and 2) to identify and validate the appropriate mix of automatic and manual control for adverse weather refueling for manned aircraft. The pictures are notions for advanced tankers concepts which would need automation to enable multiple simultaneous refueling of manned and unmanned vehicles.

Automated Aerial Refueling
Significance to Air Force

- **Unnamed Aerial Vehicles**



- **Unmanned Aerial Vehicles**
  - **Extends Range**
  - **Shortens Response for Time-Critical Targets**
  - **Maintains In-Theater Force Projection/Presence Using Fewer Assets**

- **Manned Aircraft**
  - **Enables Adverse Weather Operations**
  - **Increases Force Effectiveness**
  - **Provides Significant Improvements in Refueling Capability**

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The ability to refuel brings the same advantages to unmanned aerial vehicles as to manned fighters. It extends range, shortens response for time-critical targets, and enables an in-theater force projection to be maintained with fewer assets. The technology that will allow UAV automatic refueling can also be used to aid manned aircraft inflight refueling. Using automation, adverse weather refueling can be accomplished and refueling efficiency can be increased.

Automated Aerial Refueling
Wind Tunnel Tests

- **Controllability of UAV Receiver in the Wake of a Tanker Is of Concern**
  - **UAV Wing Span Equal to or Greater than Manned Fighters But UAVs are Lighter Weight (Susceptible to Upset)**
  - **UAV Control Power is Much Lower Than Manned Fighters (Difficult to Prevent Upset - Requires Longer to Counter Disturbance)**
  - **Langley Wind Tunnel Previously Used to Investigate Interaction of Fighters in Close Proximity (Good Correlation with Flight)**
  - **F-16 Pilots Commented that KC-135 Inboard Engine Thrust Changes Interfered with Control of Fighter During Refueling**
- **Effort Started to Measure the Effects of a Tanker's Wake on a UAV Receiver**
  - **Model of KC-135 Developed with Operating Engines Fabricated**
  - **Existing Tailless UAV Model Acquired for Test**

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Tests were conducted with 1/13th scale models at the Langley 30 x 60 ft wind tunnel to determine the flow field influence on a UAV receiver by a large tanker. For the UAVs being considered for refueling, the wing spans are equal to or greater than manned fighters; however, the vehicles are light weight and susceptible to upset from the wake of a larger aircraft. UAV control power is usually much lower than manned fighters. Thus it is difficult to prevent upsets and requires longer to counter disturbances.

NASA previously used this wind tunnel to investigate the interaction of fighters in close proximity. The data obtained showed good correlation with flight results thus the tunnel was selected for this testing.

The KC-135R model was built with operating engines to enable the investigation of thrust changes on the receiver. Model engine thrust was adjusted by using a mass ratio method to obtain representative effects. This was felt to be necessary due to comments from F-16 pilots that changes in inboard engine thrust interfered with control during refueling.

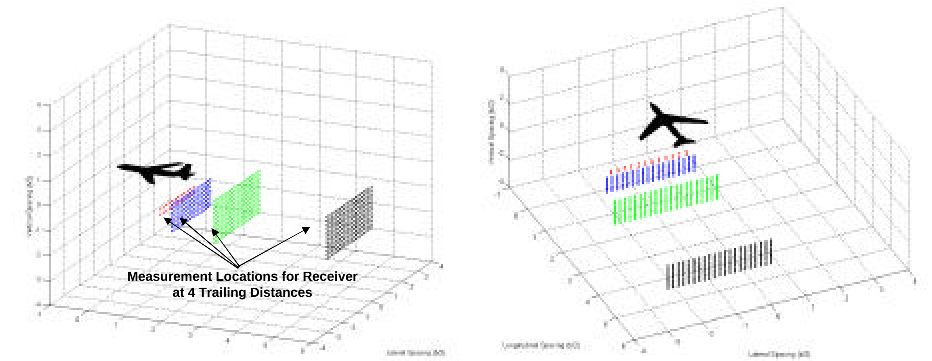
An exiting generic tailless UAV model called ICE 101, used in previous wind tunnel investigations, was selected for the unmanned receiver for these tests.

Automated Aerial Refueling

Wind Tunnel Tests Points

Test Coverage:

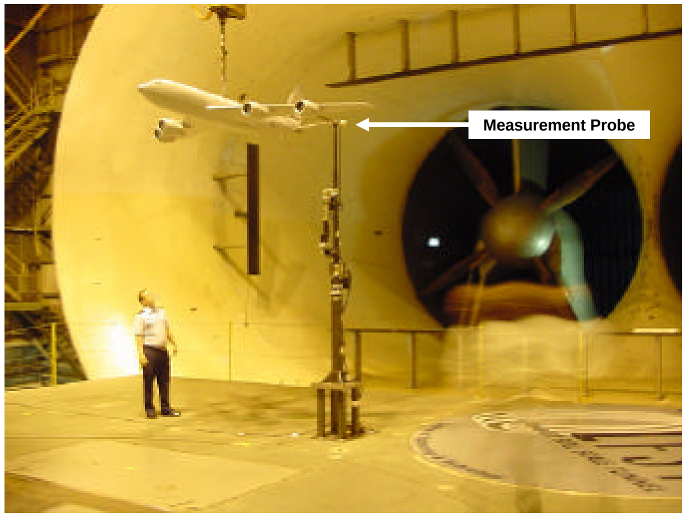
- **Wake Survey Conducted at Two Y-Z Grid Locations (Approximately 80 and 110 Feet Behind Tanker)**
- **Force and Moment Measurements at Four Y-Z Locations (80 ft, 110 ft, 200 ft, and 400 ft)**



Wind tunnel test points are shown. A grid of points at four locations behind the tanker was used to obtain force and moment data on the receiver aircraft. For the wake survey only two grid locations behind the tanker were used.

Automated Aerial Refueling

Wake Survey Setup



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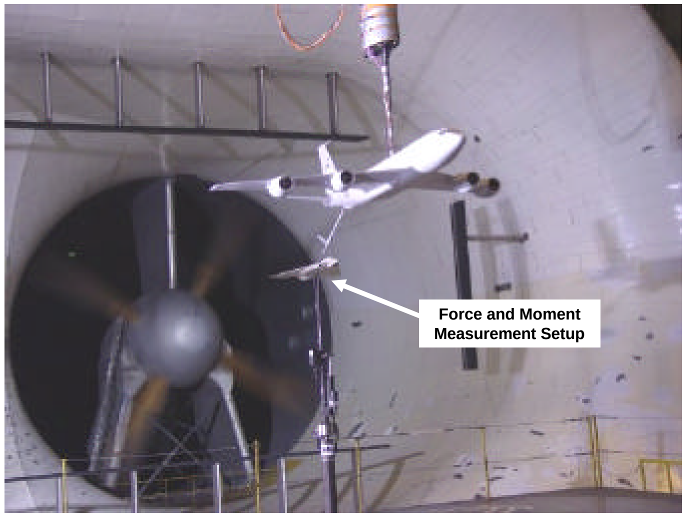
This is a photo of the wind tunnel setup for conducting a survey of the wake flow field behind the tanker. The probe is stationary for the test, and the 1/13th scale model tanker is moved to a matrix of positions in front of the probe.

Automated Aerial Refueling

Force and Moment Setup



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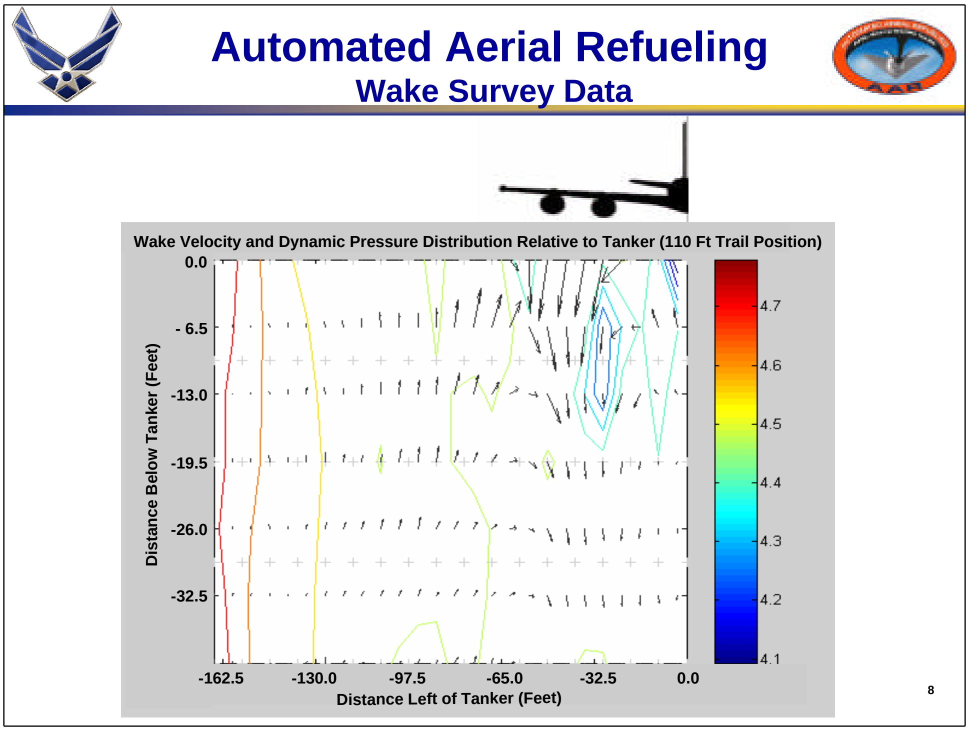
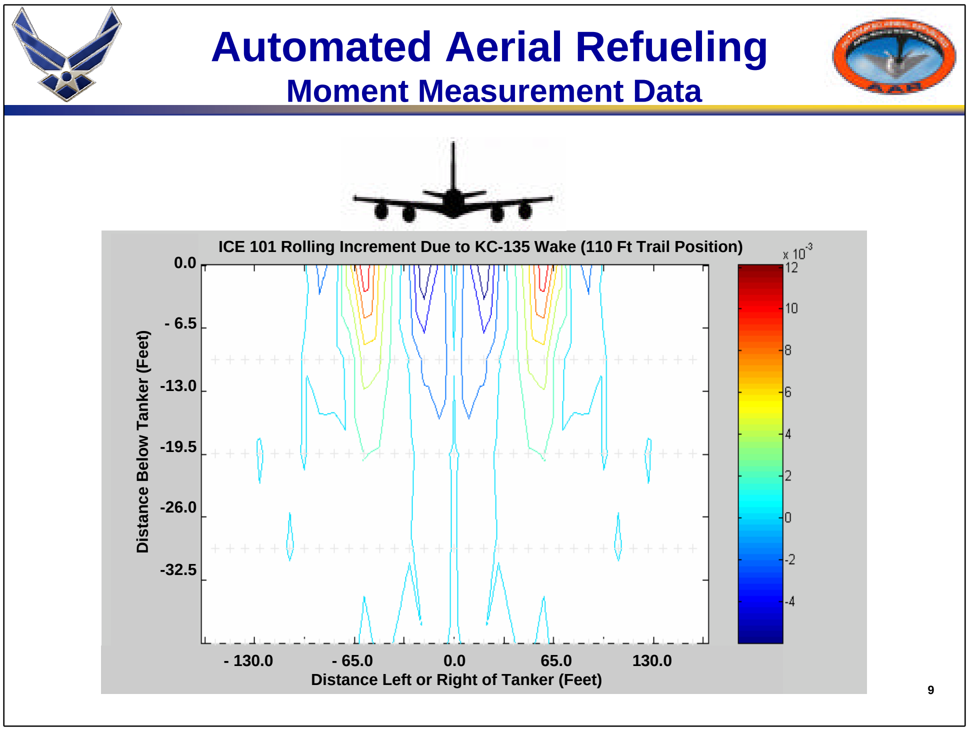
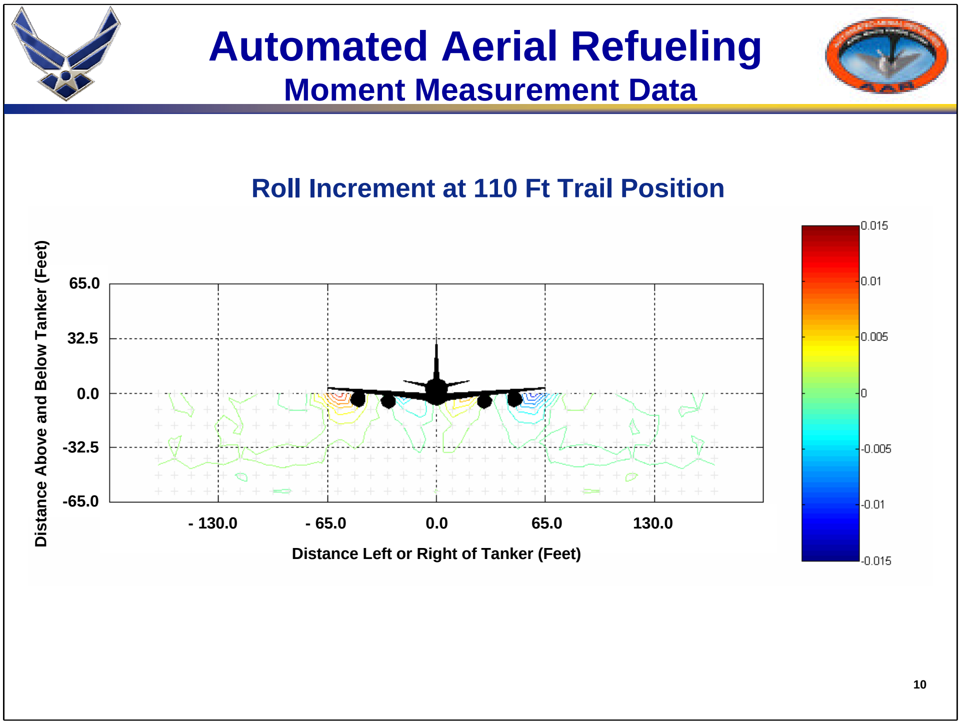
To obtain force and moment data on a receiver aircraft, the model of the vehicle is mounted in place of the wake probe. The tanker is again moved to various positions in front of the probe. The measurements are repeated without the tanker. The differences in forces and moments on the receiver are due to the tanker wake. These are recorded and used to create a tanker flow field interference model for use in simulating the refueling scenario.



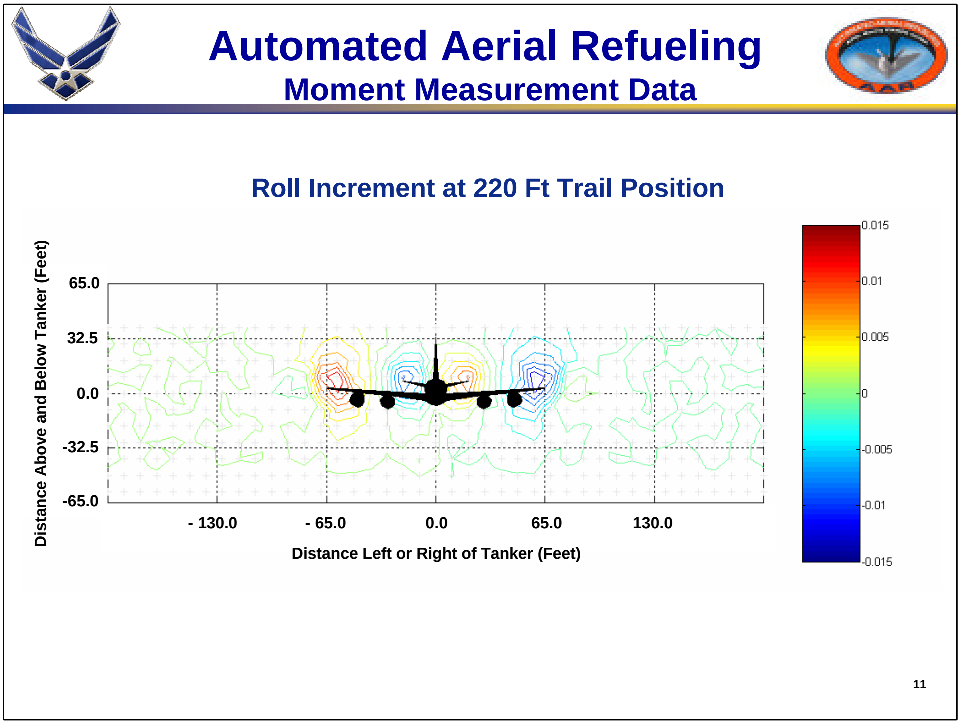
The plot shown here (with a representative semi span of the KC-135) illustrates the wake effect of the KC-135 as collected from the wake survey test. At this condition (aft of the parent vehicle by approx.100 feet full scale) this plot presents the dynamic pressure and the flow orientation of a 2-D sweep of the trailing flowfield. As can be seen from the color contour plots, there is a significant reduction in the flow velocity as a result of the airplane wake under the vehicle. Further, the interaction between the wing and the engine wakes results in a substantial down wash in between the engine nacelles. The wing tip up wash characteristic of the tip vortex is also clearly evident.



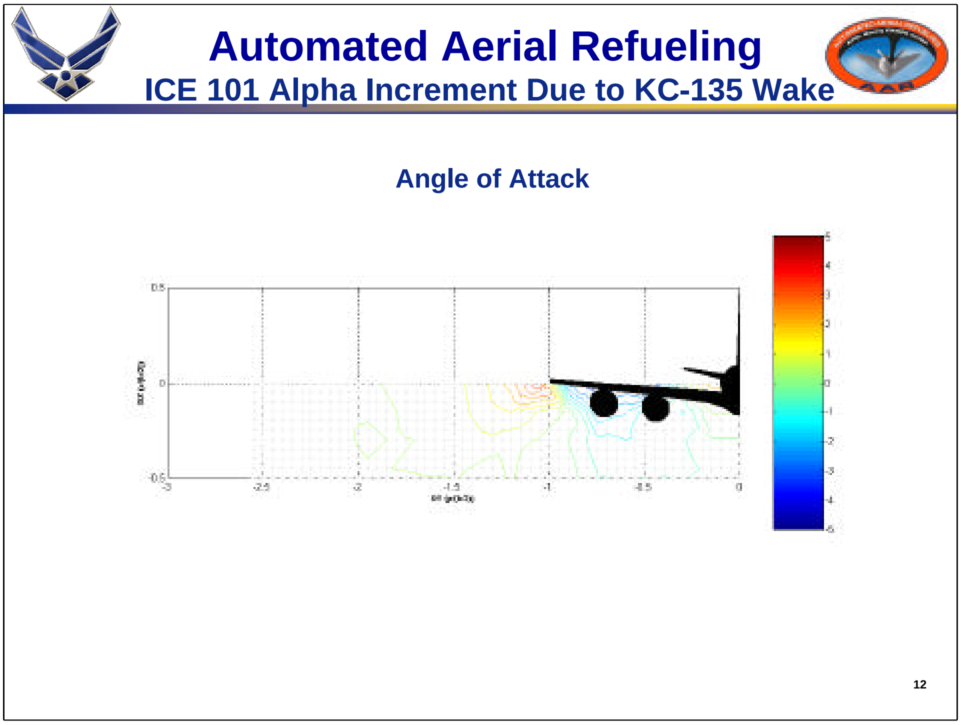
This contour plot provides actual rolling moment coefficient incremental effects of the ICE101 as it traverses in the same plane as shown in the wake survey. The largest effects occur in roll where the trail vehicle crosses between the boundaries of the up wash and downwash shown in the previous slide. Depending on the relative position of the trail vehicle, these effects in roll can become significant.



This is an expanded view of the contour plot for rolling moment coefficient incremental effects of the ICE101 at a scaled distance of 110 feet behind the tanker.



An expanded view of the contour plot for rolling moment coefficient incremental effects of the ICE101 at a scaled distance of 220 feet behind the tanker is shown.

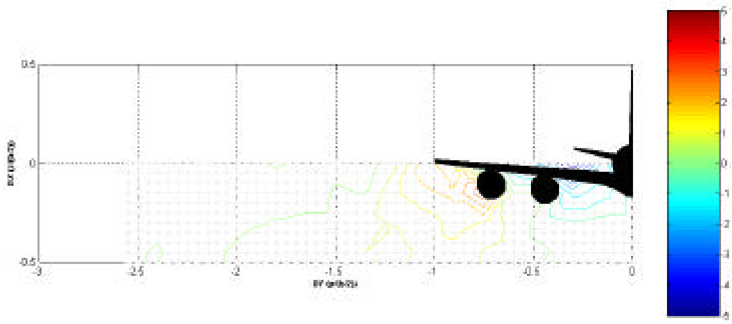


This is a contour plots for incremental angle of attack for the ICE 101 vehicle in the KC-135 wake. It indicates the change in alpha needed to hold the ICE in position at each grid point behind the tanker.

Automated Aerial Refueling

ICE 101 Beta Increment Due to KC-135 Wake

Angle of Side Slip



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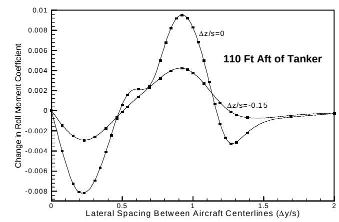
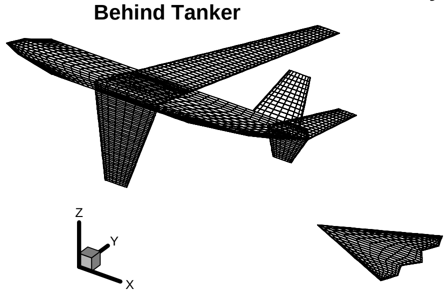
This is a contour plots for incremental angle of side slip for the ICE 101 vehicle in the KC-135 wake. It indicates the change in beta needed to hold the ICE in position at each grid point behind the tanker.

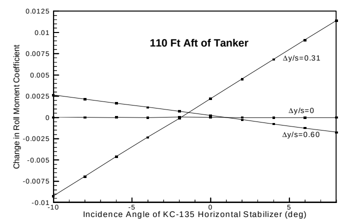
Automated Aerial Refueling
CFD Modeling and Data

Computational Fluid Dynamics (CFD) Complete on Tanker with Tailless UAV Receiver

- **Showed Horizontal Stabilizer position has effect on UAV**
  - **Largest Effect at Stabilizer edge**
  - **Smallest Effect Below and Directly Behind Tanker**







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A CFD analysis of the flow field effects on the ICE vehicle was conducted to determine the positions of most interest on which to concentrate wind tunnel measurements. Engine effects were not included in the computations. The analysis showed the significance of the horizontal stabilizer location on the trailing vehicle, and highlighted the need to pick the proper stabilizer flight trim value for the wind tunnel tests. CFD results showed good agreement with wind tunnel data.

Automated Aerial Refueling
Research Simulation Development

Aerial Refueling Simulation With Manned and Unmanned Receivers Under Development

- **"D-Six" Non-Proprietary Off-The-Self Simulation Environment That Runs on a Single PC Being Used**
- **Interface Established with "Infinity Cube" (Pilot Immersed Visualization)**
- **KC-135 & KC-10 Boom Models Operating**
  - ✓ Boom Operator Station
  - ✓ Automated Boom Control
- **Provisions for Tanker Turbulence Influence on Receiver (As Soon as Wind Tunnel Derived Model is Available)**
- **Provisions for Inclusion of Refueling Drogue Model**

D-Six Simulation

Infinity Cube Simulation

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AFRL is developing an aerial refueling research simulation capability. A commercial off-the-self desktop simulation software package called D-Six was selected as the basis for this simulation capability. The capability will include a boomer station, boom models, tanker models, tanker turbulence influence on the receivers, and multiple manned and unmanned receivers. A future development will be the addition of a drogue model for probe/drogue refueling investigations.

Automated Aerial Refueling
Research Simulation Use

- **Explore, Evaluate, and Quantify Benefits of Automation Concepts for Aerial Refueling**
  - Safety During Inclement Weather or Low Altitude
  - Time to Cycle Through a Group of Receivers
- **Develop Automatic Sequencing Concepts for Multi-Point Refueling**
- **Conduct Man-in-the-Loop Evaluations**
- **Potential for Drogue Stabilization Evaluations**
  - Requires Drogue Dynamic Model to Represent Motion Behind Tanker
  - Stabilizations Concept Preliminary Design

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The simulation will be used to explore, evaluate, and quantify benefits of automation concepts for aerial refueling. Automatic sequencing concepts for multi-point refueling can be developed in the desktop environment and easily transitioned to a man-in-the-loop evaluation. With dynamic drogue models, drogue stabilization concepts can be examined.

Automated Aerial Refueling

Examples of Automatic Maneuvering

Single Vehicle Positioning for Refueling

Multiple Vehicle Positioning for Refueling

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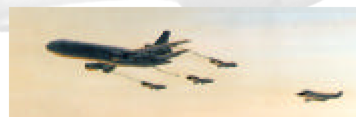
Two examples of the way a UAV may be automatically positioned for refueling in the future. In the first sequence, a single vehicle establishes a formation with the tanker by flying to a trailing position off the right wing. Next it moves to a precontact position directly behind the tanker. After stabilizing at precontact, it moves to the refueling position. The sequence is then reversed with the vehicle moving to a formation position on the left wing after refueling.

In the second sequence, four UAVs are refueling. As one UAV moves from the refueling position over to the left wing, the closest vehicle on the right wing moves into the contract position and the last vehicle on the right moves over to the closest right wing formation position.

Automated Aerial Refueling
Summary

- Automation Can Provide Significant Improvements in Refueling Capability and Efficiency
- The AAR Research Simulation Under Development by AFRL Allows Evaluation of Advanced Refueling Designs
- Concepts Developed in Desktop Simulation Environment can be Quickly Moved to a Man-In-The-Loop Simulation Environment for Boomer, Tanker Pilot, and UAV Controller Evaluations
- Concepts Developed for Automated UAV Refueling have Direct Applications to Manned Aircraft Refueling
  - Automatic Adverse Weather Rendezvous,
  - Situational Awareness and Collision Avoidance for Simultaneous Multiple Receivers
  - Drogue Stabilization Concepts for Turbulent Conditions



Capability Allows AFRL to Explore, Evaluate, and Quantify Benefits Of Aerial Refueling Automatic Concepts

Automation can provide significant improvements in refueling capability and efficiency. Concepts developed for automated UAV refueling have direct applications to manned aircraft refueling. The AAR research simulation under development by AFRL allows evaluation of advanced refueling designs. Concepts developed in the desktop simulation environment can be quickly moved to a man-in-the-loop simulation environment for boomer, tanker pilot, and UAV controller evaluations. This capability allows AFRL to explore, evaluate, and quantify benefits of aerial refueling automatic concepts.